

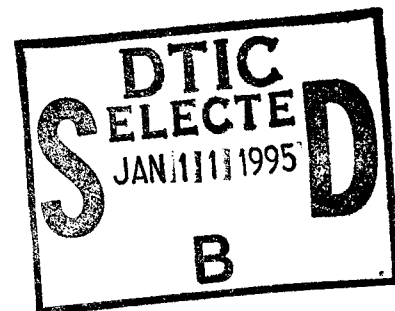
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INFLUENCES OF FILM STRUCTURES ON LASER DAMAGE THRESHOLDS

by

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This article takes $\text{TiO}_2/\text{SiO}_2$ and $\text{ZrO}_2/\text{SiO}_2$ film systems as examples and studies the influences of different film structures such as $A(\text{HL})^m\text{HG}$, $A[(2p+1)\text{HL}]^m(2p+1)\text{HG}$, as well as $A[H(2q+1)L]^m$, and so on, on laser damage threshold values. At the same time, it combines studies on measurements of optical losses and the effects of protective film thicknesses, making a preliminary probe into laser damage mechanisms as associated with optical thin films.

Key Terms: Optical Thin Films; Laser Damage; Optical Losses

I. FORWARD

Laser damage associated with thin films is the result of mutual effects between lasers and thin films. It involves the two aspects of the lasers and the thin films. A precise knowledge of the empirical rules associated with these two aspects is advantageous for setting forth the mechanisms of laser damage associated with thin films and elevating laser damage threshold values associated with film layers^(1,2).

This article takes $\text{TiO}_2/\text{SiO}_2$ and $\text{ZrO}_2/\text{SiO}_2$ multiple layer media reflective films as an example and studies the influences on laser damage threshold values of different film system structures, such as, $A(\text{HL})^m\text{HG}$, $A[(2p+1)\text{HL}]^m(2p+1)\text{HG}$, as well as $A[H(2q+1)L]^m\text{HG}$. It was discovered that, following along with increases in the thicknesses of high refractive index media layers, optical film system laser damage threshold values monotonically drop. However, following along with increases in the thicknesses of media layers with low refractive indices, the laser damage threshold values first obtain, monotonically, improvements of relatively great amplitude. Following that,

when $(2q+1) \geq 7$, the relevant film system laser damage threshold values abruptly drop far below the standard film system $A(HL)^{mHG}$.

On the basis of results from preliminary experiments on thickness effects, measurements of optical losses were combined and a preliminary probe was done into the mechanisms of laser losses associated with optical thin films.

II. EXPERIMENTS

1. Sample Preparation: All samples were evaporated and plated onto a K_9 glass base. The film system designs, technical manufacturing conditions, and film material refractive indices were as shown in Table 1.

2. Experimental Methods: Laser damage experimental equipment was as shown in Fig.1. Experimental data are set out in Table 2. Damage tests selected for use the 1-on-1 method, that is, on the surface of samples, one laser irradiation only was done on the same location, no matter whether or not this location was destroyed. The damage status associated with samples was determined by the observations of a high power microscope placed at the back. Damage threshold values were defined according to traditional threshold values. The formula representing them is⁽³⁾:

$$F_{th} = \frac{[E_{max}(ND) + E_{min}(D)]/2}{A},$$

In the equation, $E_{max}(ND)$ is the highest energy at which samples do not sustain damage. $E_{min}(D)$ is the lowest

energy at which samples sustain damage. A is the area of irradiation faculae on the surface of samples.

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Table 1 Coating design deposition parameters and refractive indices of the samples investigated ($\lambda=1.06 \mu\text{m}$)

| No. | Material | design | | deposition parameters | n |
|-----|--|--------|-------------------------------|---|--------------------------|
| | | (p, q) | $A[(2p+1)H(2q+1)L]^s(2p+1)HG$ | | |
| 1 | HfTiO ₂ LiSiO ₂ | (0, 0) | $A(HL)^3HG$ | EB evaporation $T_s=200^\circ\text{C}$ $T_{\text{baking}}=400^\circ\text{C}$ | $n_H=2.40$ $n_L=1.46$ |
| 2 | | (1, 0) | $A(3HL)^3HG$ | | |
| 3 | | (2, 0) | $A(5HL)^3HG$ | | |
| 4 | | (0, 1) | $A(H3L)^3HG$ | | |
| 5 | | (0, 2) | $A(H5L)^3HG$ | | |
| 6 | | (1, 3) | $A(H7L)^3HG$ | | |
| 7 | HfZrO ₂ LiSiO ₂ | (0, 0) | $A(HL)^3HG$ | EB evaporation $T_s=200^\circ\text{C}$ $T_{\text{baking}}=200^\circ\text{C}$ | $n_H=1.90$ $n_L=1.46$ |
| 8 | | (1, 0) | $A(3HL)^3HG$ | | |
| 9 | | (2, 0) | $A(5HL)^3HG$ | | |
| 10 | | (0, 1) | $A(H3L)^3HG$ | | |
| 11 | | (0, 2) | $A(H5L)^3HG$ | | |
| 12 | | (0, 3) | $A(H7L)^3HG$ | | |

Table 2 Experimental parameters of the damage testing

| | |
|--------------------|--------------------|
| wavelength | 1.06 μm |
| mode | TEM ₀₀ |
| pulse width (FWHM) | 10 ns |
| spotsize $1/e^2$ | 44 μm |

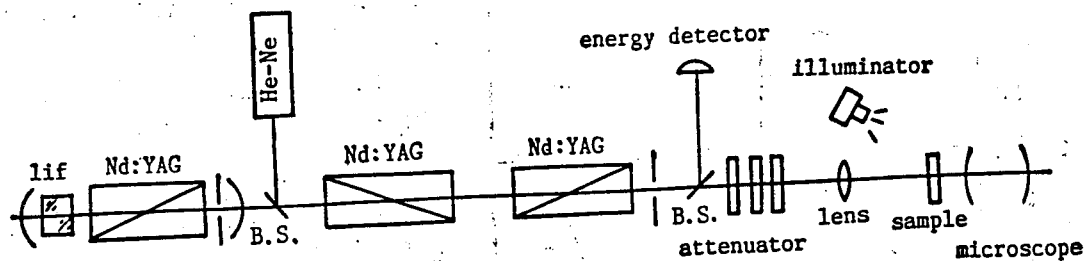


Fig. 1 Experimental Setup for damage testing

The choice was made to use pulse photothermal deviation techniques to measure the absorption(4,5) of experimental

film or coating systems. The test equipment was a colinear type of arrangement, that is, pump light (Nd:YAG, $\lambda = 1.06 \mu\text{m}$) and probe light run parallel to each other and approach colinearity⁽⁶⁾. This is as shown in Fig.2. This type of method to measure light absorption associated with multi-layer media films or coatings is sensitive to 10^{-5} . Its repetition accuracy is better than 10%. The film or coating system overall integral scattering measurements were carried out on a laser thin film scattering measurement device test manufactured by the institute in question. This instrument takes He-Ne lasers as the measurement light sources. It opts for the use of optical modulation weak signal synchronous locked phase techniques. Sensitivity reaches 10^{-5} . Relative measurement errors are better than 15%^(7,8).

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III. RESULTS AND DISCUSSION

The results of measurement tests on laser damage threshold values for thin film samples which were measured as well as for optical losses were as shown in Table 3. If one takes these results and represents them in the form of curves, then, they are as shown in Fig.3. From Table 3 and Fig.3, it is possible to see that:

1. Laser damage threshold values clearly depend on the structure of film or coating systems. The general laws are: Following along with increases in the thicknesses of high refraction index media layers, laser damage threshold values monotonically decrease. However, following along with increases in the thickness of media layers with low refraction indices, the laser damage threshold values first monotonically obtain improvements of a relatively large amplitude. After that, when $(2q+1) \geq 7$, the laser damage

threshold values associated with film or coating systems abruptly drop far below the damage threshold values associated with the standard $A(HG)^3HG$ film or coating system.

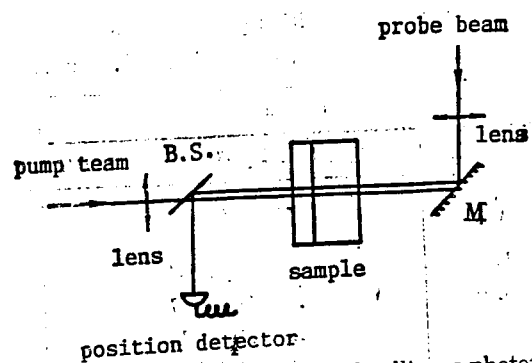


Fig. 2 Schematic illustration of pulsed collinear photothermal deflection technique

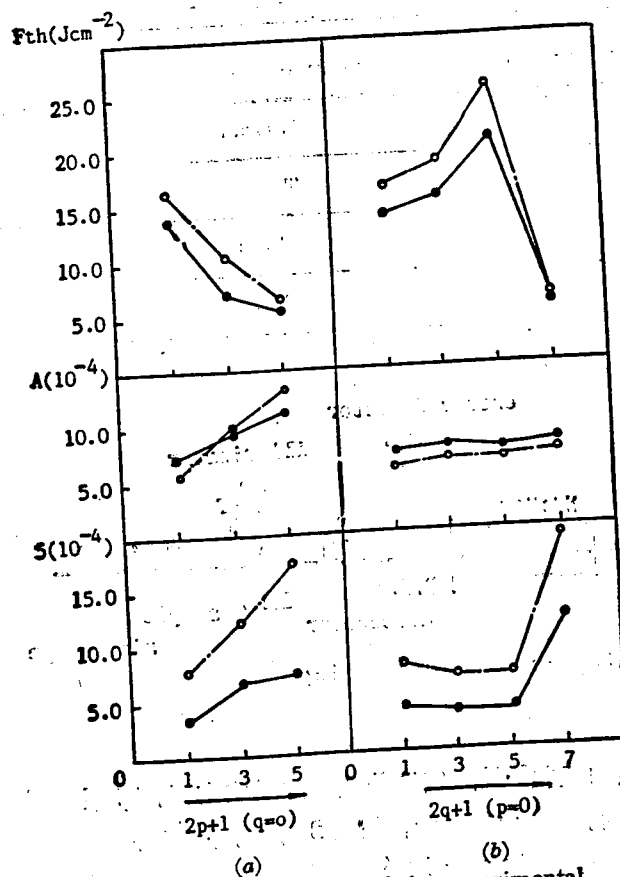


Fig. 3 Representation of the experimental results in table 3

○— TiO_2/SiO_2 ; ●— ZrO_2/SiO_2

2. Absorption and scattering losses also have a relatively strong dependency relationship with film or coating system structures. The general laws are: Following along with increases in the thicknesses of media layers with high refractive indices, sample absorption and scattering both monotonically increase. However, following along with increases in the thickness of media layers with low indices of refraction, on one hand, sample absorption is basically unchanged. On the other hand, sample scattering first shows a slight drop. After that, it rises very quickly and abruptly. This forms a comparison for the abrupt drop in damage threshold values discussed before.

An analysis of the experimental results discussed above makes it possible to reach a number of preliminary conclusions.

1. System absorption and system scattering associated with media layers having high indices of refraction make key contributions to overall absorption and overall scattering in film or coating systems.

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Table 3 Measured damage thresholds and optical losses of the samples investigated

| date \ sample | S_1 | S_2 | S_3 | S_4 | S_5 | S_6 |
|----------------------|-----------------|-----------------|----------------|-----------------|-----------------|----------------|
| $F_{th}(J\ cm^{-2})$ | 13.8 ± 1.8 | 7.0 ± 1.6 | 5.1 ± 1.2 | 15.2 ± 1.8 | 20.3 ± 2.0 | 6.0 ± 3.2 |
| $A(10^{-4})$ | 7.1 ± 0.5 | 9.5 ± 0.8 | 11.2 ± 1.0 | 7.6 ± 0.7 | 7.4 ± 0.5 | 7.8 ± 0.7 |
| $S(10^{-4})$ | 3.28 ± 0.27 | 6.58 ± 0.72 | 7.3 ± 0.81 | 3.15 ± 0.22 | 3.01 ± 0.21 | 10.4 ± 4.3 |
| date \ sample | S_7 | S_8 | S_9 | S_{10} | S_{11} | S_{12} |
| $F_{th}(J\ cm^{-2})$ | 16.2 ± 1.9 | 10.3 ± 3.1 | 6.4 ± 2.8 | 18.4 ± 1.6 | 25.1 ± 1.8 | 5.8 ± 3.3 |
| $A(10^{-4})$ | 5.6 ± 0.6 | 9.8 ± 1.2 | 13.2 ± 1.8 | 6.2 ± 0.6 | 6.4 ± 0.8 | 6.9 ± 0.7 |
| $S(10^{-4})$ | 7.83 ± 0.25 | 12.1 ± 0.31 | 17.3 ± 2.8 | 6.65 ± 0.19 | 6.70 ± 0.20 | 19.2 ± 3.4 |

2. Optical film or coating system laser damage threshold values follow along with increases in the thickness of media layers with high indices of refraction and monotonically drop. The causes can be understood like this. Increases in the thickness of media layers with high indices of refraction lead to increases in absorption. Cross section structures associated with films or coating media with high indices of refraction are normally generated in the form of cylinders or columns. Following along with increases in the thickness of film or coating layers, the cylinder form structures get coarser and coarser, and pits or holes become more and more numerous⁽⁹⁾.

3. Optical film or coating system laser damage threshold values follow along with increases in the thickness of media layers with low indices of refraction and achieve improvements of relatively great amplitude. This phenomenon is capable of being understood as the SiO_2 film or coating's low refraction index materials and the cross section structures associated with the majority of thin films or coatings being different from each other. This is generated by particle states. The structures are meticulously uniform⁽⁹⁾. Because of this, in multiple layer media film or coating systems, SiO_2 has improving effects on boundary structures. This type of improvement effect increases along with increases in film or coating thickness. When $2q+1=5$, it reaches the optimum. At this time, if one advances the increases still further in layer thicknesses of media with low indices of refraction, by contrast, due to stress effects, within multiple layer media films or coatings, a good number of extremely small striations are formed. This causes film or coating system scattering to obviously increase, and damage threshold values drop a large amount.

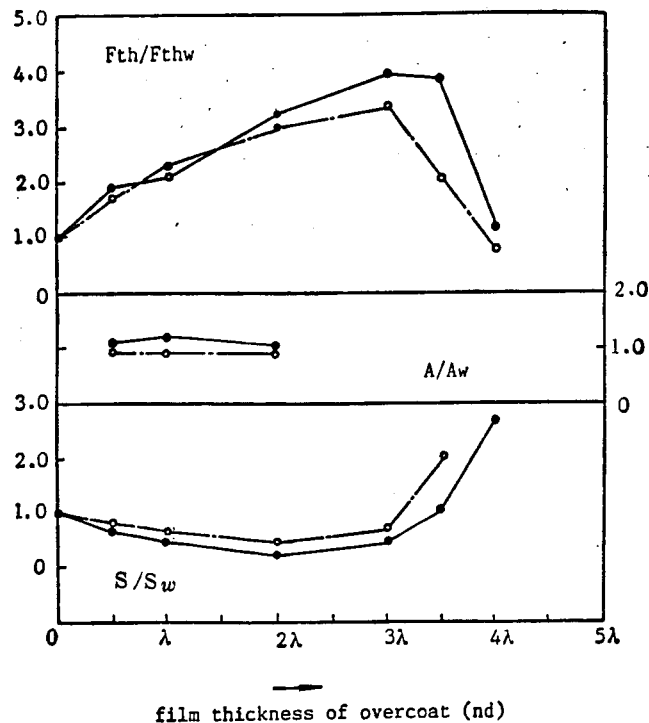


Fig. 4 Film thickness effect of SiO₂ overcoats:
 ○—TiO₂/SiO₂ HR; ●—ZrO₂/SiO₂ HR.
 (Index w indicates measured results of the
 samples without overcoat)

This article also studied thickness effects associated with highly reflective membranes and protective membranes or films. The relevant experimental results are as shown in Fig. 4. Comparing Fig. 4 and Fig. 3(b), it is not difficult to see that the two possess unusually similar patterns or regularities. This phenomenon is explained by the fact that highly reflective membranes or films possess protective effects associated with protective films or coatings and have similar mechanisms to increases in film or coating system damage thresholds from low refractive index film layers in multiple layer media films or coatings. Low refractive index SiO₂ films improve micro-structures associated with high refractive index media layers adjacent to them.

IV. CONCLUDING REMARKS

This article studied the influences of film or coating systems on multiple layer media reflective film optical losses and laser damage threshold values. In conjunction with this, it combined experimental results associated with film thickness effects on highly reflective film protective membranes or coatings. It made preliminary probes into relevant mechanisms and arrived at a number of preliminary conclusions. These conclusions have a definite instructive meaning for the design and manufacture of strong laser thin films. Measurements and tests on damage threshold values associated with film or coating systems are also capable of supplying references to personnel concerned.

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